

# Quantification of Stenotic Mitral Valve Area With Magnetic Resonance Imaging and Comparison With Doppler Ultrasound

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<b>OBJECTIVES</b>	The purpose of this study was to evaluate the reliability of the pressure half-time (PHT) method for estimating mitral valve areas (MVAs) by velocity-encoded cardiovascular magnetic resonance (VE-CMR) and to compare the method with paired Doppler ultrasound.
<b>BACKGROUND</b>	The pressure half-time Doppler echocardiography method is a practical technique for clinical evaluation of mitral stenosis. As CMR continues evolving as a routine clinical tool, its use for estimating MVA requires thorough evaluation.
<b>METHODS</b>	Seventeen patients with mitral stenosis underwent echocardiography and CMR. Using VE-CMR, MVA was estimated by PHT method. Additionally, peak E and peak A velocities were defined. Interobserver repeatability of VE-CMR was evaluated.
<b>RESULTS</b>	By Doppler, MVAs ranged from 0.87 to 4.49 cm <sup>2</sup> ; by CMR, 0.91 to 2.70 cm <sup>2</sup> , correlating well between modalities ( $r = 0.86$ ). The correlation coefficient for peak E and peak A between modalities was 0.81 and 0.89, respectively. Velocity-encoded CMR data analysis provided robust, repeatable estimates of peak E, peak A, and MVA ( $r = 0.99, 0.99$ , and $0.96$ , respectively).
<b>CONCLUSIONS</b>	Velocity-encoded cardiovascular magnetic resonance can be used routinely as a robust tool to quantify MVA via mitral flow velocity analysis with PHT method. (J Am Coll Cardiol 2004;44:133-7) © 2004 by the American College of Cardiology Foundation

Clinical assessment of the severity of mitral stenosis (MS) depends on both the presence of symptoms and mitral valve orifice area (1). Evaluation of mitral valve area (MVA) with Doppler echocardiography provides rapid, accurate analysis of valve disease and serves as a practical gold standard for clinical evaluation. For MVA analysis, the Doppler pressure half-time (PHT) method has advantages over the alternative techniques of Doppler continuity equation method, two-dimensional planimetry, and the invasive Gorlin method because of its simplicity and robustness (2).

Velocity-encoded cardiovascular magnetic resonance (CMR) is an established method for quantifying flow through cardiac valves (3-6). It can accurately characterize valvular regurgitation (7-9), pressure gradients, and stenotic aortic valves (10,11). However, the reliability of CMR for quantifying MS has not been defined, particularly in conjunction with PHT methods. Accordingly, we implemented a velocity-encoded CMR version of the PHT method to estimate the orifice area of stenotic mitral valves for comparison with paired Doppler ultrasound data.

## METHODS

**Patients.** Seventeen patients (13 women age 45 to 85 years, mean 64 years) with documented MS undergoing clinically indicated echocardiographic exams were recruited. Two exhibited pure MS; 15 had mixed mitral/other valve disease (predominantly mitral regurgitation, 73%). Patients with general contraindications to CMR were excluded (12). The study protocol received local institutional review board approval. Each patient was imaged with CMR and echocardiography successively, but in random order. An experienced CMR technologist and ultrasonographer acquired images independently, blind to results of the other, without physician supervision to mimic working clinical laboratory conditions.

**Transthoracic echocardiography.** Cardiac Doppler studies were obtained using 128-element phased-array imaging systems with a 3.5-MHz 128-element phased-array imaging transducer (Acuson Sequoia, Mountainview, California) and Doppler at 2.0 MHz. Conventional clinical procedures for echocardiography were employed with analysis performed immediately after data recording.

Mitral valve area was determined from continuous-wave Doppler spectra of transmitral flow obtained from the apical PHT four-chamber view by fitting velocity points over the range of early diastole with software resident on the imager, in accordance with standard laboratory practices that use the linear segments of the data (13). The mitral valve area was estimated as  $MVA = 220/PHT$ . Measurements of PHT and MVA were based on a representative heartbeat selected

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**Abbreviations and Acronyms**

AF	= atrial fibrillation
CMR	= cardiovascular magnetic resonance
MS	= mitral stenosis
MVA	= mitral valve area
PHT	= pressure half-time
ROI	= region of interest
$V_{ENC}$	= velocity encoding (maximum) value

by the experienced sonographer in blind fashion independent of physician review or concurrence. The E- and A-wave velocities also were measured with the software cursor tool at the bedside.

**CMR velocity encoding imaging.** Each patient was imaged with a 1.5-T MRI (Intera CV, Philips Medical Systems, Best, the Netherlands) using a five-element phased-array receive coil. A breathhold, steady-state gradient echo cine sequence (balanced-fast field echo or balanced-turbo field echo) was performed first in multiple views (e.g., four-chamber, vertical long-axis) to provide the qualitative functional exam of the mitral valve. With the use of the free-breathing, retrospectively gated velocity-encoding CMR technique, quantitative flow images were acquired (slice thickness 8 mm, echo time 3.0 ms, repetition time 6.0 ms, flip angle 30°, 2 averages, field of view 350 mm, matrix 128 × 256, 30 phases per RR interval). The velocity-encoded CMR series were performed in the left ventricular short-axis plane oriented parallel to the mitral valve plane, positioned 1.5 cm from the valve plane toward the apex (Fig. 1a). Typically, each scan required about 3.5 min, depending on heart rate. The maximum encoding velocity limit ( $V_{ENC}$ ) was set to 1.5 m/s ("through plane"). If velocity aliasing occurred, the images were reacquired with a higher  $V_{ENC}$ .

Images were transferred to a workstation (EasyVision R5.1, Philips Medical Systems) for quantitative flow analysis. A region of interest (ROI) was drawn on each of the 30

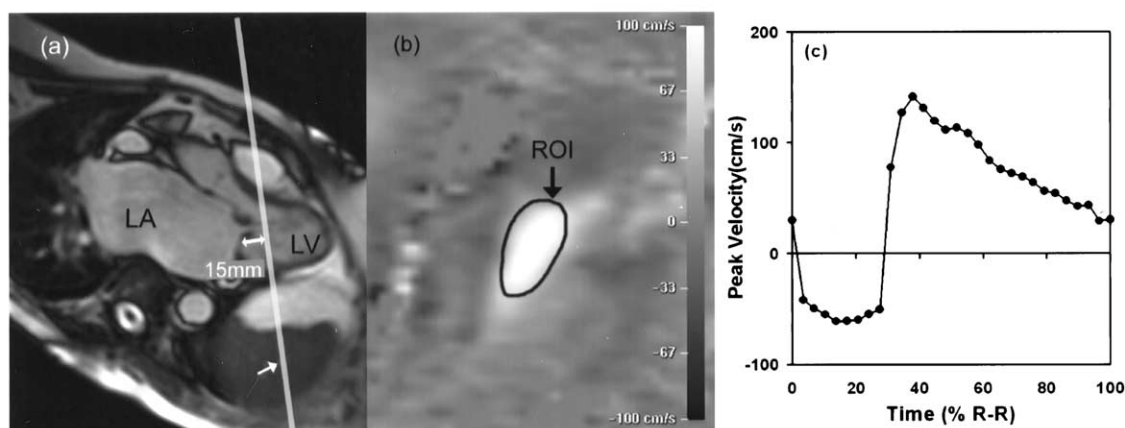
phases of the cine, including the mitral flow jet to identify peak velocity (Fig. 1b). The peak flow velocity values within each ROI at each phase were exported to a spreadsheet and a plot of peak velocity versus time was constructed over the cardiac cycle (Fig. 1c). The peak E-wave and peak A-wave velocities during diastole were defined from the flow velocity curve. To quantify the PHT objectively, a least-squares fitting technique was used. For fitting a simple linear equation, all the data points from the peak early filling velocity during diastole (i.e., peak E) to the linear portion of the flow velocity curve were included, following the approach used by the sonographer (Fig. 2). For patients in atrial fibrillation (AF), all the data points during diastole were included to measure the PHT. As with ultrasound, MVA was estimated as 220/PHT. All CMR values were compared double-blind with Doppler ultrasound measurements.

**Reproducibility.** Interobserver reproducibility for CMR measurements was also evaluated in ten randomly-selected patients. Two observers independently defined ROIs, measured peak E and A, estimated PHT, and calculated MVA. Repeated measurements were compared.

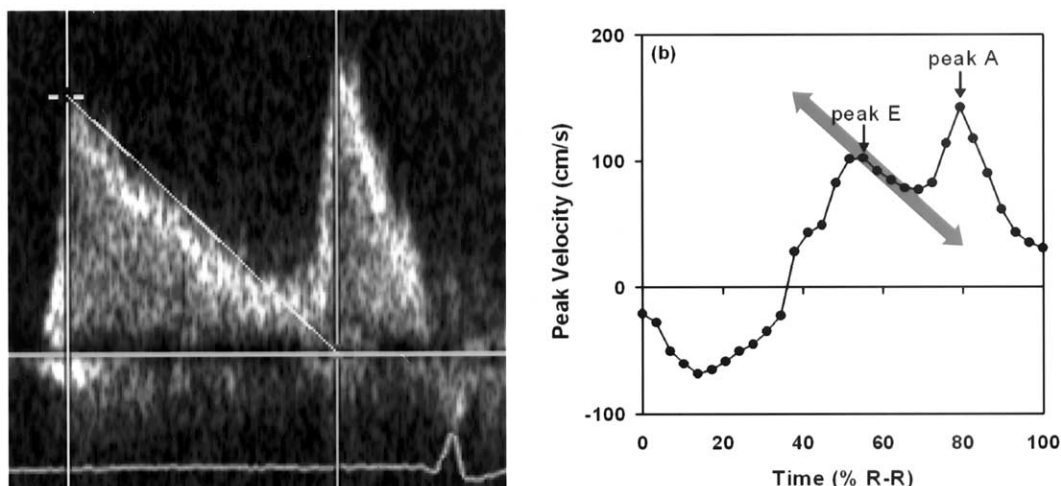
**Statistical analysis.** To determine the relationship between CMR and echocardiography, a Pearson coefficient of correlation was tested with linear regression analysis. A two-tailed p value of <0.05 was considered significant. Bland-Altman analysis (14) was performed to compare the agreement of Doppler and CMR measurements. To evaluate interobserver reproducibility for CMR measurements, Pearson coefficients of correlation and concordance correlation coefficients (15) were calculated.

**RESULTS**

In the 17 patients with MS, echocardiographic assessment of stenosis ranged from trace to severe. Associated signs of MS, such as mitral valve leaflet thickening, mitral regurgitation, and enlarged left atrium, were readily observed on



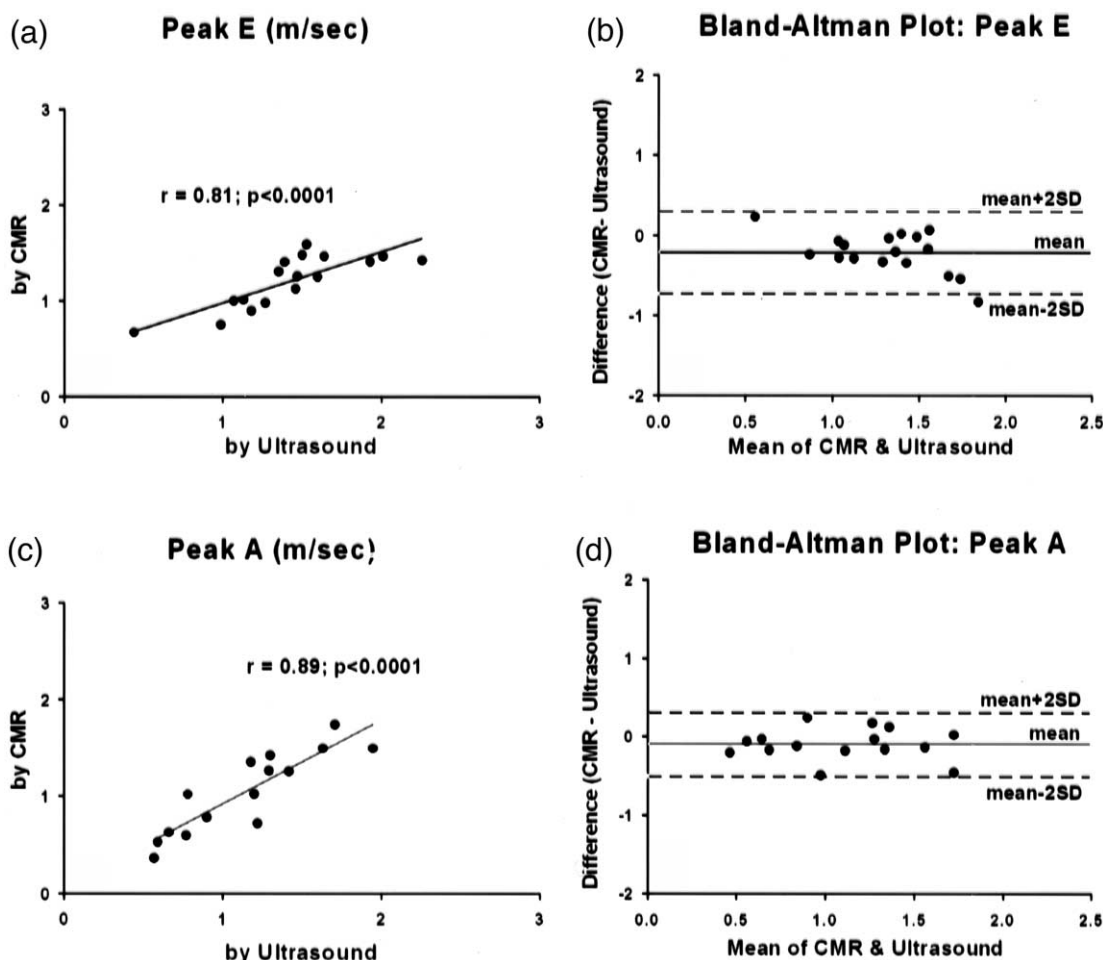
**Figure 1.** (a) The velocity-encoded cardiovascular magnetic resonance (CMR) image plane was positioned 1.5 cm from the mitral valve plane toward the apex. (b) A region of interest (ROI) in the velocity image includes the mitral flow jet allowing identification of the peak velocity. (c) Plot of the peak velocity versus time over the cardiac cycle measured by velocity-encoded CMR: note absence of the peak A-wave (Afib). LA = left atrium; LV = left ventricle.



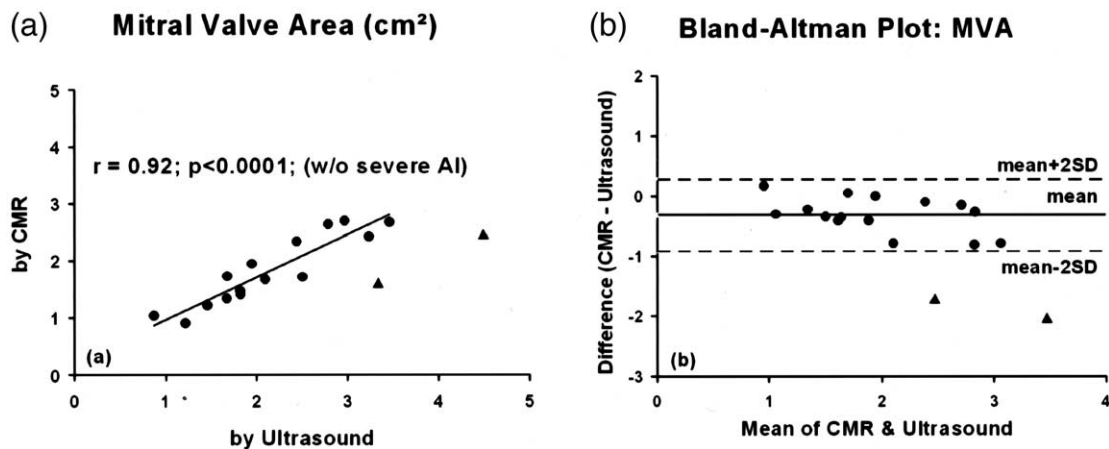
**Figure 2.** (a) Doppler estimation of the pressure half-time (PHT). (b) All velocity-encoded cardiovascular magnetic resonance data points from peak E to the linear portion of the flow velocity curve were included to determine the PHT by simple linear regression.

the cine gradient-echo magnitude images. Two patients with severe MS were in chronic AF, and two patients exhibited severe aortic valve insufficiency.

Figure 1a shows a long-axis image with the intersecting plane selected for velocity-encoded imaging, and Figure 1b shows the phase image of that selected short-axis plane with



**Figure 3.** Comparison of cardiovascular magnetic resonance (CMR) results to echocardiography: peak E is the maximum velocity at E-wave (a and b), and peak A is the maximum velocity at A-wave (c and d). (a) Scatter-plot of the peak E obtained by CMR versus echocardiography. (b) Bland-Altman plot of the mean results of both methods related to the mean difference. (c) Scatter-plot of the peak A obtained by CMR versus echocardiography. (d) Bland-Altman plot of the mean results of both methods related to the mean difference. SD = standard deviation.



**Figure 4.** The mitral valve area (MVA) estimated using pressure half-time approach: comparison of velocity-encoded cardiovascular magnetic resonance (CMR) results to echocardiography. **(a)** MVAs obtained by CMR correlated well with those by ultrasound. **(b)** Bland-Altman plot of the mean difference and 2 standard deviation (SD) limits of MVA estimated by both methods. **Triangles** = patients with AI; other abbreviations as in Figure 3.

the ROI circumscribing the mitral flow jet. The peak velocity values within each sequential ROI comprised the mitral flow profile. Figure 1c shows CMR recordings of peak velocity versus time curve for a patient with severe MS and AF.

**Peak E velocity and peak A velocity.** The peak E velocity in 17 patients ranged from 0.44 to 2.26 m/s for echocardiography and 0.67 to 1.59 m/s for velocity-encoded CMR. The peak A velocity (15 patients) ranged from 0.57 to 1.95 m/s measured by echocardiography and 0.36 to 1.74 m/s by CMR. Figures 3a and 3c show the correlation of peak E velocity measured from CMR and Doppler ( $r = 0.81$ ,  $p < 0.0001$ ) and the strong correlation of peak A velocity defined from CMR and echocardiography ( $r = 0.89$ ,  $p < 0.0001$ ). The mean difference of peak E between modalities was 0.22 m/s (SD = 0.26 m/s), and limits of agreement were (−0.73, 0.29) m/s (Fig. 3b). The mean difference of peak A was 0.10 m/s (SD = 0.20 m/s), and limits of agreement were (−0.51 to 0.31) m/s (Fig. 3d).

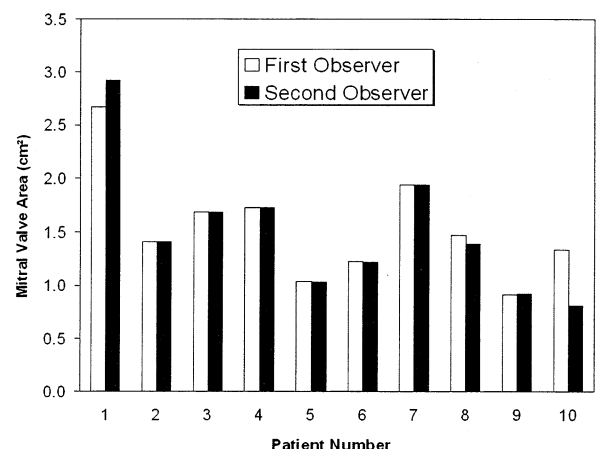
**Pressure half-time and mitral valve area.** The PHT calculated from echo Doppler measurements ranged from 49.0 to 252.0 ms; MVA ranged from 0.87 to 4.49 cm². The PHT obtained by velocity-encoded CMR ranged from 81.5 to 242.6 ms and MVA from 0.91 to 2.70 cm². The correlation between the PHT determined by the two modalities was significant ( $r = 0.86$ ,  $p < 0.0001$ ). Furthermore, the intermodality correlation of the MVA calculated using PHT correlated well ( $r = 0.80$ ,  $p = 0.0001$ ). The mean difference of MVA between the two modalities was 0.50 cm² (SD = 0.59 cm²) and limits of agreement were (−1.68 to 0.68) cm². If data from the two patients with severe aortic regurgitation were excluded, the relationship correlated even more strongly ( $r = 0.92$ ,  $p < 0.0001$ ) (Fig. 4a), with the mean difference of MVA between modalities being 0.32 cm² (SD = 0.30 cm²) with limits of agreement (−0.91 to 0.28) cm² (Fig. 4b).

**Reproducibility.** Figure 5 illustrates excellent concordance between MVA analyses by two independent observers ( $r =$

0.96,  $p < 0.0001$ ) for ten patients with MS. The CMR valve size estimates by each observer also correlated well with Doppler ( $r = 0.94$  and  $0.89$ ;  $p < 0.001$ ). The component measurements of peak E, peak A, and PHT also correlate well between observers ( $r = 0.99$ ,  $0.99$ , and  $0.83$ , respectively;  $p < 0.01$ ). Table 1 summarizes the comparison of all the interobserver measures with both the Pearson correlation coefficient ( $r$ ), and the reproducibility index, concordance correlation coefficient.

## DISCUSSION

This study demonstrates the ability of velocity-encoded CMR to quantify MVA in patients with MS using the PHT method in a manner directly analogous to that employed in echocardiographic laboratories with Doppler echocardiography. For evaluation of MS, important strengths of CMR are that visualization of the spatial configuration of the mitral valve is excellent and quantification of trans-valvular flow jets is unre-



**Figure 5.** Interobserver reproducibility of mitral valve area using velocity-encoded cardiovascular magnetic resonance. The mitral valve area for ten patients analyzed by first (white bars) and second (black bars) observer is shown. Overall correlation between observers was  $r = 0.96$  ( $p < 0.0001$ ), as detailed in Table 1. Abbreviations as in Figure 3.



**Table 1.** Comparisons Between Repeat Measurements of Peak Velocities, Pressure Half-Time, and Mitral Valve Area With Velocity-Encoded Cardiovascular Magnetic Resonance

	Peak E	Peak A	PHT	MVA
r (p value)	0.99 (<0.0001)	0.99 (<0.0001)	0.83 (0.003)	0.96 (<0.0001)
CCC (95% CI)	0.99 (0.99–0.99)	0.99 (0.97–0.99)	0.78 (0.40–0.94)	0.94 (0.82–0.98)

CCC = concordance correlation coefficient; CI = confidence interval; MVA = mitral valve area; Peak A = peak velocity at A-wave; Peak E = peak velocity at E-wave; PHT = pressure half time; r = Pearson correlation coefficient.

stricted by echo windows. Although velocity-encoded CMR has been used clinically for some time (16–19), few studies have dealt with methods for *quantification* of valve disease other than regurgitation. The results of this study confirmed the findings of other studies regarding valve flow velocities and pressure gradients, but importantly extend the methodology to direct calculation with CMR of valve areas, which is critical for patient management.

Although echocardiographic implementation of the PHT method serves as a simple and practical gold standard for clinical evaluation of MS in routine patient care situations, some limitations exist (20). For example, in cases of aortic insufficiency, ventricular diastolic filling retrograde from the aorta might cause the mitral gradient to decline prematurely, decrease PHTs artificially, and cause an overestimation of MVA. Indeed, most studies have reported that PHT overestimates MVA in the setting of coexisting moderate to severe aortic insufficiency (21,22). We observed that CMR tended to mildly underestimate peak velocities as compared with echocardiography. Insufficient temporal resolution might distort the flow velocity as a function of the phase of the cardiac cycle, particularly with respect to the greater temporal sampling frequency of echo Doppler data. Fortunately, recent reports indicate that CMR temporal resolution may be substantially increased without loss the accuracy in complex flow patterns (23).

In conclusion, these data indicate that MVA can be quantified with the PHT method robustly and routinely with a single velocity-encoded CMR acquisition. Furthermore, these methods, which can be substantially automated to provide repeatable and objective assessments, are easily adaptable to any MR scanner. Together with recent demonstrations of the robustness of related MR methods for computation of aortic valve areas (11), we propose that the clinical utility of CMR for routine assessment of valvular disease might be viewed as equivalent to that of echocardiography.

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